Land-Use Planning and the Interchange Community

J.C. FREY, H.K. DANSEREAU, R.D. PASHEK, and A. TWARK, respectively, Professor of Land Economics, Associate Professor of Sociology, Professor of Business Administration, and Assistant Professor of Business Administration, Pennsylvania State University

This paper discusses land-use adjustments at interchange locations and the importance of land-use regulation and control in preserving highway efficiency. The analysis covers alternative objectives of land utilization, problems associated with conflicting economic interests, hypothesis deserving of empirical investigation, and the current status of research in the land-use planning field. The paper seeks to develop and promote studies that will aid in the protection of highway investments from private exploitation.

• THE OBJECTIVE of this paper is threefold: (a) to delineate the general problem of land-use planning for highway protection, (b) to suggest a methodology for research into land-use planning at interchange locations, and (c) to propose research needs for the development of improved land-use planning standards.

GENERAL PROBLEM

Although many studies have been made to determine the impact of highway improvement on economic growth, very few have been undertaken to show the effect of new growth, when it does occur, on the long-run efficiency of highways. It is the thesis of this presentation that economic growth detracts from the ability of highways to accommodate traffic. To the extent that highway improvements foster economic development, they may very well bring about their own obsolescence.

The question that many highway officials ask is whether new highways can be protected by regulating the use of land at interchange locations. Because access control in many states has only limited application, can comprehensive land-use planning help solve the problem? This query presents a challenge to the researcher in the land-use planning field.

Possible Linkages

Whether land-use planning can provide protection for highways depends on whether there is a causal relationship between differential forms of land management and changes in highway capacity. If there is no linkage between the two, there is no hope for a remedy through land-use planning. On the other hand, if there is a linkage and it can be clearly defined, land-use planning holds promise of providing a workable solution.

The development of a transport system grows out of a demand for the movement of goods and persons between particular locations. Land management units (parcels of real property owned or managed as separate estates) are basic units from which all flows of goods and persons originate and to which all flows of goods and persons are destined. These units are not self-contained; they are highly interdependent, and their interdependence requires that they have access to a transportation system.

Of the various forms of transportation provided, society places a somewhat unique responsibility on highways. Broadly interpreted, highways are expected to furnish every land mangement unit with a direct transportation outlet. This contention is not intended to rule out the importance of other forms of transportation, which most certainly are needed and must be considered in an over-all analysis of resource mobility, but to point out how sensitive highway use is to changes in the land resource base and to delimit this special relationship for research consideration.

This paper proposes that land management units alter both the practical capacity of roadways and the volume of traffic constituting the flow. First, the private thoroughfare or approach of each land management unit forms an intersection with some segment of the public highway system. The impact of this intersection is to lower practical capacity. The amount that capacity is lowered depends, among other things, on the design characteristics of the intersection, the volume and direction of traffic flowing through the intersection, and the composition of the traffic. These factors in turn, are a function of the physical, social, and economic attributes of the land management unit.

Second, each land management unit influences the size of the traffic stream flowing through the public highway network. Volume additions to various links in the network are a function of the amount of traffic generated and attracted by the land management unit and the location of the land management unit with respect to other such interacting units.

Each volume addition by a land management unit not only pushes the traffic load of the system closer to practical capacity but also indirectly affects capacity itself. It does this by changing the kind and number of vehicles moving through established intersections in the highway network. Thus, the number of land management units attached to a segment of highway, the characteristics of these land management units, and their location with respect to one another are associated with the ability of a roadway to accommodate traffic.

Conversion of farm land to industrial-urban uses is often accomplished by subdivision. This increases the number of land management units and creates new points of access to the existing highway network. Each new unit must have an outlet. Even though a spatial expansion of the system takes place in the form of new streets, capacity is affected by the juncture of these streets with existing roads. Further, the traffic generated and attracted by the new management units increases volume throughout the system and, in this way, chips away at the practical capacity of the roadway.

In some instances, changes in the characteristics of land management units occur without an increase in number of access points. Examples are the replacement of a single household dwelling with an apartment building, the change from a farm to an industrial plant, or even the expansion of an industrial plant. Although no new approaches are created, and frequently no new streets are built, the practical capacity of the highway is altered because more and possibly different kinds of vehicles are entering and leaving and adding to the restriction of the traffic flow. Subdivision regulation is not necessarily a guarantee that highways will be protected.

Finally the spatial arrangement of land management units influences the mileage of different kinds of highways needed to satisfy a particular transport demand. Long distances between units with a high level of interaction call for more miles of high-capacity highways than do shorter distances. Conversely, given the mileage and location of different classes of highways in an area, from the viewpoint of minimizing total restriction to designed traffic flow, there probably exists an optimum spatial arrangement of land management units.

Normative Formulation

Traditionally, maximum economic growth has been accepted as a goal of community planning; and a desirable pattern of land use and development has been defined as one that would contribute to the realization of this economic objective. Because costs of highway development usually are broadly shared, few attempts have been made to plan land use exclusively for the purpose of protecting highways. Highway construction simply has been expected to keep pace with whatever demands local economic activities might have created.

An alternative criterion of planning, when public investment in highways becomes the objective of decision, is the minimizing of the need for new highway construction.

If this criterion is accepted as the goal of planning, then a desirable pattern of land use is one that generates and attracts traffic at volumes that can be efficiently absorbed by the existing roadway. Unrealistic as this goal may seem to some at first glance, it is undoubtedly implicit in access control, acquisition of easements, setback control, and other protective measures.

The analysis of this presentation is built around the objective of permitting only those kinds of land development that highway networks can accommodate. The principle of selection is that the number, kind, or location of land management units shall not create traffic demands that will bring about congestion.

It is recognized that this objective may have to be relaxed in the actual administration of highway programs, but it is necessary to designate a fixed criterion of this nature if research into roadside planning is to proceed in a systematic manner. If planning standards can be established to help approach this goal, they can be used in practice to reach any solution that policy decisions may dictate. Moreover, the thesis here is not that the norm of highway protection must take precedence over other economic objectives of people in planning for their future. Plans for maximum economic growth in a community may be found to complement plans for highway protection, or the two may stand in a relationship of direct conflict. In either event, the means and consequences of both types of planning need to be understood if policy decisions are to be made. If society wishes to assign a higher priority to highway protection than to roadside development, planning for the former may serve to set forth restrictive limits within which alternative models for economic growth can be developed. Research into highway planning seeks not to make the policy decisions but to provide enough information so that intelligent choices can be made.

Remedial Analysis

Once basic causal relationships are understood and "ideal" land-use plans for highway protection are designed, appropriate control mechanisms need to be considered. This concluding phase of inquiry deals with social and political arrangements that may help implement and enforce planned programs of land use and development. In a sense these institutionalized arrangements establish the rules of the game. The rules are imposed by local, state, and federal governments, by special districts, authorities, associations, councils and commissions, and by a wide variety of informal social groups. The arrangements are known by such titles as land acquisition via right of eminent domain; police powers, including zoning and subdivision regulation; preferential taxation; compensatory payments; lease and deed restrictions; education; and even organizational codes. It is important to know which of these protective devices are effective and when they are institutionally feasible. The selection of appropriate controls and the granting of rights to use these controls pose problems of no small dimensions.

This last phase of the land-use planning problem rounds out the general research design. The methodology that follows is not addressed to remedial measures, but is confined to the diagnostic and normative phases of the analysis. Such focus of attention is not to suggest that research into institutionalized controls is of lesser importance but to emphasize that remedial measures may be accomplished with greater proficiency after objective land-use planning standards have been determined.

RESEARCH METHODOLOGY FOR LAND-USE PLANNING IN INTERCHANGE COMMUNITIES

Interchange Community as Study Unit

The unit of observation proposed for research into land-use planning around highways is the interchange community. Although any attempt at definition of such a unit is hazardous, it may be taken to represent an area of land immediately surrounding the intersection of a controlled access highway with some open access route. It is at these locations that economic growth tends to cluster and that encroachment from ribbon business developments seems to be most severe.

Along many controlled access highways, without service plazas, interchange communities are depended on almost entirely to provide the economic needs of through traffic. These communities are frontiers of economic development and in some instances have grown into incorporated boroughs or cities. Planning in these communities holds the possibility of guiding land-use adjustments at a very early stage in their growth. However, before practical planning can occur, it must be preceded by both capacity determinations and models for the accommodation of new land uses.

Determination of Absorption (Surplus) Capacity

The designed capacity (D_c) of a segment of highway in an interchange community is the maximum number of vehicles that can pass through the segment, considering safe speeds commensurate with engineering specifications. This capacity is a direct function of (a) the width of the highway (e.g., two as opposed to four lanes), (b) the obstructions (curves, hills, etc.), and (c) the type of surface of the highway. Other factors such as the volume of traffic turning on or off the segment, the proportion of different types of vehicles in the traffic stream, plus any other unique or special variables are viewed in this context as being constant. Designed capacity, therefore, is a theoretical maximum which is unlikely to be attained in reality. Designed capacity may be written as:

$$D_c = f(w, o, s) + e$$

in which

w = width;

o = obstructions;

s = surface; and

e = other variables, treated as being constant.

The practical capacity (P_c) of a segment of highway, similarly, is a function of the width, obstructions, and type of surface, as is designed capacity; however, the factors held constant in the first formulation are now viewed as being variable. Accordingly, practical capacity is directly a function of (a) the volume of traffic that enters the highway segment through a certain type of intersection, (b) the volume that leaves the highway segment, (c) the proportion of different classes of vehicles in the traffic stream, and (d) any other unique or special factors affecting the segment of highway in question.

These factors may be viewed as restrictions to the designed traffic flow of the segment; therefore, practical capacity may be viewed as equal to the designed capacity minus the volume of traffic restricted or hindered (denoted by H):

$$P_c = D_c - H.$$

By classifying various public and private intersections (for instance those with stop signs, traffic lights, and yield right-of-way) and determining the volume of traffic that is restricted by various amounts of traffic entering and leaving these intersections, and also taking into account the product mix or proportion of different classes of vehicles in the traffic stream, as well as any special factors that restrict traffic on the segment, the total H can be estimated. When the value of H is subtracted from designed capacity, the remainder is the practical capacity of the segment.

Thus, if

V_e = type of intersection with a given volume of traffic entering the highway segment;

V_l = type of intersection with a given volume of traffic leaving the highway segment;

M_x = product mix or proportion of different classes of vehicles in the traffic stream; and

E = a unique or special factor which restricts traffic on a highway segment;

Then:

$$H = \begin{bmatrix} V_{e_1} \text{ restricts } a_1, & V_{e_2} \text{ restricts } a_2, & \ldots, & V_{e_n} \text{ restricts } a_n \\ V_{l_1} \text{ restricts } b_1, & V_{l_2} \text{ restricts } b_2, & \ldots, & V_{l_n} \text{ restricts } b_n \\ M_{x_1} \text{ restricts } c_1, & M_{x_2} \text{ restricts } c_2, & \ldots, & M_{x_n} \text{ restricts } c_n \\ E_1 \text{ restricts } d_1, & E_2 \text{ restricts } d_2, & \ldots, & E_n \text{ restricts } d_n \end{bmatrix}$$

As an illustration:

V_{e_1} restricts a_1 means: "a given volume of traffic entering the segment at intersection type (1) restricts a certain amount of traffic (a_1) on the segment."

V_{l_2} restricts b_2 means: "a given volume of traffic leaving the segment at intersection type (2) restricts a certain amount of traffic (b_2) on the segment."

M_{x_3} restricts c_3 means: "a certain proportion type (3) of vehicles in the traffic stream restrict an amount of traffic (c_3) on the segment."

E_n restricts d_n means: "a special or unique factor type (n) of the segment restricts an amount of traffic (n) on the segment in question."

Thus, given the practical capacity of a segment and the actual volume (A_v), or the average daily traffic (ADT), then the difference between the two gives the surplus or absorption capacity: $P_c - A_v = S_c$. It may be beneficial in estimating surplus capacity to obtain certain "peak" hour traffic, e.g., 8 to 10 am or 4 to 6 pm.

In any case, the actual volume of traffic on a given segment of highway for a specified time period can be thought of as being composed of four types:

1. Generated traffic— Traffic that originates within the segment, created by land management units that use both private and public intersections abutting the segment in question.
2. Attracted traffic— Traffic that terminates within the segment, attracted to both private and public intersections abutting the segment in question.
3. Local traffic— Traffic that both originates and terminates within the segment.
4. Through traffic—Traffic that neither originates nor terminates within the segment.

Given the following symbols, all traffic (A_v) on a given segment can be accounted for:

G = volume of generated traffic that goes to destinations outside the segment;
A = volume of attracted traffic that comes from points outside the segment;
L = volume of local traffic which uses the segment; and
T = volume of through traffic (residual after accounting for G, A, and L).

In equation form:

$$A_v = G + A + L + T$$

The volume G could be broken down according to almost unending kinds of land management units; however, for practical purposes and simplification five categories are used.

These include volumes of traffic generated by residential units (R), commercial units (C), industrial units (I), other units (O), and public intersections or connectors (K) abutting the segment. (Although the connectors themselves do not create the traffic flow, they can be treated as generators and attractors when they intersect the segment in question.)

Therefore knowing that the residential unit of type (1) generates an amount (gr_1) of traffic; of type (2) generates an amount (gr_2); etc., the total volume of traffic generated by all residential units of various types is $\sum_{i=1}^{n} gr_i$.

Similarly, a commercial unit of type (1) generates an amount (gc_1); of type (2) generates (gc_2) etc.; and the total volume generated by all commercial units is $\sum_{j=1}^{n} c_j$.

Continuing in like manner for I, O, and K, the volume of traffic G is the total sum of the volumes generated by these five categories. In symbolic form,

$$G = \Sigma gr + \Sigma gc + \Sigma gi + \Sigma go + \Sigma gk$$

In exactly the same manner the volume of traffic A can be classified, and by using attracted traffic in place of generated traffic the following equation summarizes the total volume of traffic attracted to the segment:

$$A = \Sigma ar + \Sigma ac + \Sigma ai + \Sigma ao + \Sigma ak$$

By using estimates for traffic generated from points within the segment to destinations within the same segment (or traffic attracted from points within the segment) the total volume of traffic that uses the segment locally may be summarized in symbolic form:

$$L = \Sigma lr + \Sigma lc + \Sigma li + \Sigma lo + \Sigma lk$$

Through traffic is the residual after G, A, and L have been determined; therefore, assuming A_V is known, through traffic may be written

$$T = A_V - (G + A + L)$$

If, however, a solution for a future A_V is desired, T may be viewed as a constant with allowance for a growth factor.

Having determined practical capacity (P_C) and given present volume (A_V), the difference is surplus or absorption capacity (S_C). There may be only one figure representing this surplus (P_C - ADT), a range of figures taking into account a pattern of variation, or several figures taking into account different times of the day or days of the week.

Accommodation of New Land Uses

Given an interchange community that has surplus capacity with respect to its present highway structure and land management units, the next problem is to decide how many and what kinds of new developments can be allowed to locate, and where they can locate, until the surplus capacity is utilized.

Further, a very important factor to be considered in the analysis is congestion. Congestion occurs when the number of vehicles attempting to travel a segment of highway exceeds the practical capacity. This may occur on many roads at certain times of the day, but on no road is it feasible to assume constant congestion. However, it is possible that constant congestion could arise if no alternative routes or modes of travel were available.

Congestion may be viewed as a forced reduction in average rate of speed, necessitating a longer time to arrive at a destination. Actually, all traffic volumes can be perceived of as a function of a certain rate of speed and a distance necessary between vehicles for safety:

$$V = f(r', d)$$

in which

V = volume per unit of time;
r′ = average rate of speed; and
d = average distance between vehicles.

The specific function is:

$$V = r'/d$$

Table 1 shows how number of vehicles per hour is related to speed and distance. At designed capacity, a steady flow of vehicles takes place at an ideal rate of speed and with a corresponding safe distance between vehicles. The specific case set forth in the table shows relationships for a 40-mph highway designed to carry 1,932 vehicles per hr safely; in which instance, practical capacity equals designed capacity. Under other conditions practical capacity would be less. The table shows that either changes in average rate of speed or average distance between vehicles would cause the maximum number of vehicles per hour ovęr the segment to be reduced to safe practical capacities.

TABLE 1

TRAFFIC VOLUME RELATED TO SPEED AND DISTANCE[a]

Average Rate of Speed (r′) (mph)	Distance Between Vehicles (d) (ft)	Volume per Hour (V)[b]
0	0	0
10	40	1,320
20	60	1,760
30	85	1,863
40	115	1,932
50	140	1,886
60	180	1,758

[a]Figures in table for illustrative purposes only.

[b]Number of cars that can pass through segment 1-mi long in 1 hr.

In the case of actual volume, the average rate of speed and the average distance between vehicles depend on many factors — origins, destination, time of day, etc. Nevertheless, if these factors are known, actual volume per hour, or per day, can be estimated. If more cars attempt to pass through a segment than can get through at practical capacity limits, congestion occurs. Congestion usually causes even fewer cars to get through than normally could. The degree or extent of congestion on a segment is directly related to the number of vehicles that attempt to travel the segment in excess of the segment's practical capacity. The greater the degree of congestion, the fewer vehicles there are that can actually pass through.

In reference to Table 1, if more than 1,932 cars attempt to pass through the segment in an hour, the rate of speed may become reduced to 30 mph, allowing only a maximum of 1,863 cars. If an even greater number should attempt to pass through, the average speed may be reduced to only 20 mph, allowing only 1,760 vehicles, etc.

The practical importance of congestion arises in deciding to what extent future traffic can be regulated so that peak loads never (or rarely) exceed practical capacity. With respect to the utilization of surplus capacity, some standards must be developed to keep congestion down to a minimum, not only on the segment in question but also, in the event of diffusion, throughout the highway connector system.

There are many different types of land management units, each contributing a certain amount of traffic volume. New land management units may or may not contribute in the same proportion as have similar units in the past. If they do, a linear function exists; if not, a nonlinear function must be considered. Nevertheless, a theoretical solution can be made, and empirical studies can be undertaken to determine the type or types of functions.

Total traffic on a segment of highway over a period of time is made up of the generation and attraction functions of land management units. For the purpose of this analysis, actual traffic was classified into four components (Appendix): generated traffic (G) attracted traffic (A), local traffic (L), and through traffic (T); and land management units

were classified into four broad categories: residential (R), commercial (C), industrial (I), and other (O). Much variation exists within each of these categories; however, to keep the central theme in focus, these oversimplifications are necessary.
Since:

$$A_v = G + A + L + T$$

Then:

$$\Delta A_v = \Delta G + \Delta A + \Delta L + \Delta T$$

A_v equals the increase in traffic through the formation of new land management units within the segment plus any change on through traffic.

Therefore, the increase in actual traffic volume for some future time period can be determined if the coefficients for the following formulations are known (or can be reasonably estimated):

$$\Delta A_v = \Delta T + \left[\begin{array}{l} \Delta G = g_1 \Delta R + g_2 \Delta C + g_3 \Delta I + g_4 \Delta O + g_5 \Delta K \\ \Delta A = a_1 \Delta R + a_2 \Delta C + a_3 \Delta I + a_4 \Delta O + a_5 \Delta K \\ \Delta L = l_1 \Delta R + l_2 \Delta C + l_3 \Delta I + l_4 \Delta O + l_5 \Delta K \end{array}\right]$$

After solving for the increase in actual volume, the next step is to solve for the decrease in practical capacity as a result of adding congestion factors to the system:

$$\Delta P_c = f(\Delta V_e, \Delta V_l, \Delta M_x, \Delta E)$$

Each time a land management unit is added to the system, actual volume will tend to increase; and practical capacity will tend to decrease, thus reducing surplus or absorption capacity. If it is desired to know how many land management units of different kinds would utilize the excess capacity, both pressures have to be considered.

Given the generative and restrictive functions subject to the constraints that the increase in actual volume plus the increase in restricted volume (or decrease in practical capacity) must equal or be less than absorption capacity, a linear programming model could be set up and solved. However, at present, this procedure is much more refined than the accuracy of the information can call for. Therefore, a much simpler approximation may be given:

$$S_c = P_c - A_v \text{ and}$$

$$S_c - (\Delta P_c + \Delta A_v) = 0$$

then,

$$\frac{S_c}{\Delta A_v + \Delta P_c} \geqq 1$$

By this equation, excess capacity is simply apportioned over the combined influences of additions and restrictions on traffic volume.

This equation can be solved for a homogeneous group of units with little difficulty. For example, if each new residential unit (R) accounts for an increase of 4 cars per day over the segment and in turn restricts practical capacity (P_c) by one; then with a surplus volume of 500 cars per day 100 new residential units could be allowed:

$$\frac{500}{4R + R} = 1$$

$$R = 100$$

Similarly, the formula could be applied in cases involving exclusively commercial, exclusively industrial, or exclusively other units.

If a select combination of units is to be considered, then a wide range of possibilities exists. However, to the extent that one has advance knowledge as to the suitability of the land around the interchange segment for various types of land management units, the combinations may be restricted primarily to a few choices. Also, as development takes place, the remaining choices may become more and more restricted.

Another consideration is the sequential pattern of development in an interchange community. For example, it is generally recognized that the industrial growth generates residential growth, which in turn generates commercial growth, which may induce more residential growth. Consequently, in deciding on how much industrial and commercial growth is to be allowed, not only must the present impact be evaluated but also the projected impact.

If the desired objective is to locate land management units so as to maximize the number of units that will utilize the excess capacity or to locate a given number and/or combination of units that will minimize resultant traffic flows, the network of origins and destinations that presently exist, as well as the likely network that would subsequently exist, must be considered. Based on this information, there may be relatively few alternatives.

Functional relations, relating trip frequencies with different kinds of land management units, could serve as guides to spatial location. Once a combination of units is derived that requires the least amount of distance to satisfy the travel needs of the public, it could be used in conjunction with the surplus volume equation, or with a linear programming model, to arrive at the number of units of each type that could be allowed while still maintaining protection for the existing highway.

PRACTICAL IMPLICATIONS FOR LAND-USE PLANNING

Assuming that relative frequency of trips between various origins and destinations can be determined and that the absorption capacity of an interchange connector can be approximated, a plan for land development along this connector can be set forth that will allow the least distance of travel to satisfy public needs. The plan can specify, by type, the maximum number of land management units that may locate without destroying the functional capacity of the roadway. The ideal situation is one that allows for an even distribution of traffic and in which land management units are nearest to the destination of their most frequent trips. If the traffic is evenly distributed and the most frequent trips are the shortest, the largest amount of new development can be accommodated in the system.

Traffic using a segment may be viewed as a weighted average of the various links making up a segment, with a link defined as the space between two intersections, private or public. A link approach is very important because the maximum through traffic that can pass over a segment is determined by the link with the lowest capacity. Congestion may occur at the access points, the first crossroad, or perhaps along a link on a section of land that would be developed to such an extent that generated volumes would exceed estimates of practical capacity.

A suggested solution in the planning for a segment is a simulation model of land management units that will maximize the developmental potential within limits feasible for highway protection. To the extent that terrain, landscape, or other factors are determinants of the specific locations of land management units, these physical factors will impose additional restrictions.

Attention could be given first to access points with the highest priority of protection. Even though commercial or industrial firms desire close access, it may not be desirable to permit them to so locate. Instead, units of low and consistent generation could be permitted, and only to an extent that congestion would seldom, if ever, be reached. The diffusion effects of subsequent growth could be simulated, and these simulated results could then be used as guides to permissible background developments.

Once the generation factors are known and priorities in protection are established, an optimum land development plan can be derived. Where effects of alternative units or combinations of alternative units are equivalent, they could be handled on a first come, first served basis. In any event, from the viewpoint of highway protection, insight can be obtained as to the specific types of abutting land management units that should or should not be permitted to locate.

Research Requirements

Essential to the formulation of a simulation model, and thereby any standards for the planning of land use around interchanges, are certain basic empirical research needs:

1. Investigations to determine the restrictive impacts of private and public intersections on practical capacity, to include variations in design, volume of traffic flowing through the intersections, and the composition of the traffic. Variations in these several factors need to be correlated with speed and distance between cars.
2. Investigations to determine the diffusion of congestion from any one point, link, or segment of a highway to another.
3. Investigations to determine the association of changes in the physical, social, and economic characteristics of land management units with changes in number of intersections per unit length of roadway, volume of traffic generated and attracted through private and public intersections, and changes in the composition of the traffic generated and attracted through intersections. Involved are investigations that will determine choice of routes in response to travel time under different levels of congestion.
4. Investigations to determine trip frequencies among various kinds of land management units.
5. Classifications of land management units with regard to their effects on practical capacity and traffic volume.
6. Classifications of land management units according to their reciprocal trip frequencies.

It may very well be that highway engineers and students of land resource use will have to join forces to accomplish these research tasks.

Appendix

Matrix of Traffic Flow

$V = G + A + L + T$

$$G = \begin{bmatrix} g_{11}r_1 + g_{12}r_2 + & \cdots\cdots\cdots & g_{1n}r_n + \\ g_{21}c_1 + g_{22}c_2 + & \cdots\cdots\cdots & g_{2n}c_n + \\ g_{31}i_1 + g_{32}i_2 + & \cdots\cdots\cdots & g_{3n}i_n + \\ g_{41}o_1 + g_{42}o_2 + & \cdots\cdots\cdots & g_{4n}o_n + \\ g_{51}k_1 + g_{52}k_2 + & \cdots\cdots\cdots & g_{5n}k_n + \end{bmatrix}$$

$$A = \begin{bmatrix} a_{11}r_1 + a_{12}r_2 + & \cdots\cdots\cdots & a_{1n}r_n + \\ a_{21}c_1 + a_{22}c_2 + & \cdots\cdots\cdots & a_{2n}c_n + \\ a_{31}i_1 + a_{32}i_2 + & \cdots\cdots\cdots & a_{3n}i_n + \\ a_{41}o_1 + a_{42}o_2 + & \cdots\cdots\cdots & a_{4n}o_n + \\ a_{51}k_1 + a_{52}k_2 + & \cdots\cdots\cdots & a_{5n}k_n + \end{bmatrix}$$

$$L = \begin{bmatrix} l_{11}r_1 + l_{12}r_2 + & \ldots\ldots\ldots\ldots\ldots l_{1n}r_n + \\ l_{21}c_1 + l_{22}c_2 + & \ldots\ldots\ldots\ldots\ldots l_{2n}c_n + \\ l_{31}i_1 + l_{32}i_2 + & \ldots\ldots\ldots\ldots\ldots l_{3n}i_n + \\ l_{41}o_1 + l_{42}o_2 + & \ldots\ldots\ldots\ldots\ldots l_{4n}o_n + \\ l_{51}k_1 + l_{52}k_2 + & \ldots\ldots\ldots\ldots\ldots l_{5n}k_n + \end{bmatrix}$$

T = Through traffic, current or projected.

Matrix of Traffic Restriction

$H = f(V_e, V_l, M_x, E)$

$$V_e = \begin{bmatrix} a_{11}v_1i_1 + a_{12}v_2i_1 + \ldots\ldots\ldots\ldots a_{1n}v_ni_1 + \\ a_{21}v_1i_2 + a_{22}v_2i_2 + \ldots\ldots\ldots\ldots a_{2n}v_ni_2 + \\ \vdots \\ a_{n1}v_1i_n + a_{n2}v_2i_n + \ldots\ldots\ldots\ldots a_{nn}v_ni_n \end{bmatrix}$$

in which

a_{11} = amount of segment traffic restricted by type of intersect i_1 with v_1 traffic entering the segment from i_1.

$$V_l = \begin{bmatrix} b_{11}v_1i_1 + \ldots\ldots\ldots\ldots\ldots\ldots b_{1n}v_ni_1 + \\ \vdots \\ b_{n1}v_1i_n + \ldots\ldots\ldots\ldots\ldots\ldots b_{nn}v_ni_n \end{bmatrix}$$

in which

b_{11} = amount of segment traffic restricted by type of intersect i_1 with v_1 traffic leaving the segment via i_1.

$$M_x = \begin{bmatrix} c_{11}m_{x_1} + c_{12}m_{x_2} + \ldots\ldots\ldots\ldots c_{1n}m_{x_n} \end{bmatrix}$$

in which

c_{11} = amount of segment traffic restricted because of the proportion m_{x_1} of different classes of vehicles in the traffic flow.

E = assumed value due to unique factors.